Air Flow through Woven Stainless Steel Mesh

Abstract

It was known that a mesh screen placed across an airflow will have an evening effect, distributing both the velocity and pressure across the screen, however this effect had not been quantified and the effect of different mesh geometries was unknown. It was desired to understand the relationship between airflow velocity, the pressure behind the screen and the free hole area of the screen.

It was concluded that the developed pressure is proportional to the velocity for a given free hole area, and inversely proportional to free hole area for a given velocity. Screens with less free hole area also maintain laminar flow on exit for a greater distance.

Introduction

Various samples of stainless steel woven mes h were tested on a custom designed test apparatus to determine the effect of the screen geometry on the air flowing through, particularly the relationship between the velocity of the air exiting the screen and the pressure behind the screen. Screens of varying *free hole areas* (FHA) were tested and a regression analysis of the results was performed to produce a mathematical relation for screen pressure as a function of velocity and FHA.

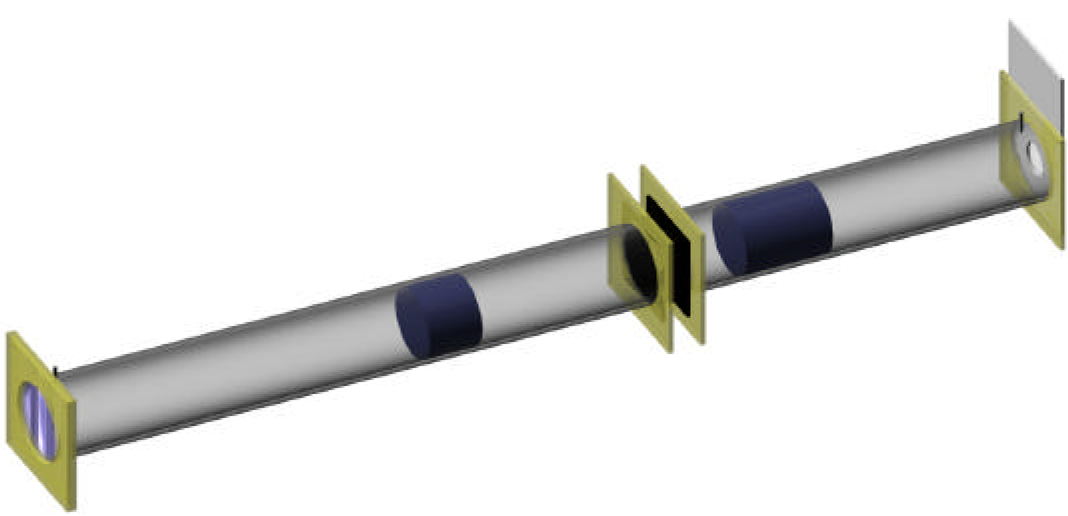
The resulting relation was: $$P = \frac{V^{1.50}}{42.8 \times 10^{2.59A}}$$

Where P is the screen pressure, V is the velocity and A is the FHA. This gives a power law dependence with velocity, and an inverse power law dependence with FHA. As expected the screen pressure increases with velocity, and decreases with increasing FHA. These results were as expected since with increased velocity comes increased drag, while a greater FHA gives a greater open area and impedes the flow less.

This result does not take into account boundary conditions at FHA of 0% and 100% and is ideally only valid between 30 – 55 % FHA but can probably be extended 10% in either direction with reasonable confidence. Also, due to the limit of reading of the apparatus used, ***** errors reached 25 – 50 % in the lower velocity measurements. Geometrical effects of the apparatus, such as using a square rather than cylindrical tube, and the varying diameters of mesh wires were not investigated. Mesh diameters varied little between meshes, varying from 0.0026 – 0.0075 of an inch and in this range the differences between the different diameters seemed negligible.

Experimental Procedure

The tests were carried out on a purpose built test apparatus constructed from acrylic tubing. This transparent construction allowed easy observation of flow patterns within the device. It consisted of an orifice-plate for flow measurement, an axial flow fan, several sections of honeycomb for flow straightening, and the screen holder. Measurements were taken from two pressure taps situated at either end inside the orifice plate and screen holder.



See Appendix for more detailed drawings of apparatus.

Components

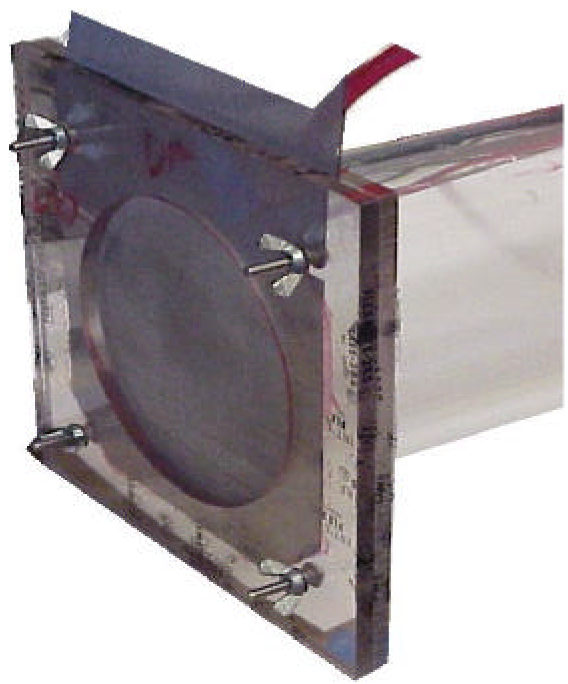
Fan	Dayton 70 cfm (maximum) axial flow fan
Pressure Meter	Energy Conservatory Digital Pressure Gauge (DG-2) two channel, time averaging, limit of reading 0.1 Pa
Anemometer	Airflow TA 2 anemometer / thermometer, limit of reading 5-20 fpm
Orifice Plate	2 inch diameter hole, centred
Sample	4 inch diameter disc of mesh, additional material on edges for clamping

Calibration

Before it could be used for any experiments, the rig was calibrated to obtain a relationship between the orifice pressure and the flow velocity since the pressure meter is more convenient than the anemometer. To calibrate the rig a series of velocity / pressure readings were taken and graphed, obtaining a fitted curve and equation. The pressure meter can provide time averaged results, whereas the anemometer gives instantaneous (and often wildly fluctuating results) results, thus the pressure meter is preferred.

1. For calibration purposes, an additional length of tubing was at tached in place of the test screen. This had a hole drilled in the upper surface to admit a hot -wire anemometer for velocity measurements.
2. The fan was cycled through it's power range and readings taken periodically
3. Once obtained, the readings were graphed and any areas that seemed anomalous were re-measured.
4. Using Microsoft Excel, a power function ($y=Ax^b$) trendline was fitted to the points and the equation obtained.
5. From this equation it was then possible to calculate the velocity given a pressure reading from the orifice.

Screen Characterisation



Once calibrated it was possible to run the actual tests on the screens. Each screen in turn was placed between the two front plates and measurements were taken at the orifice plate and just behind the screen for the fan's entire velocity range.

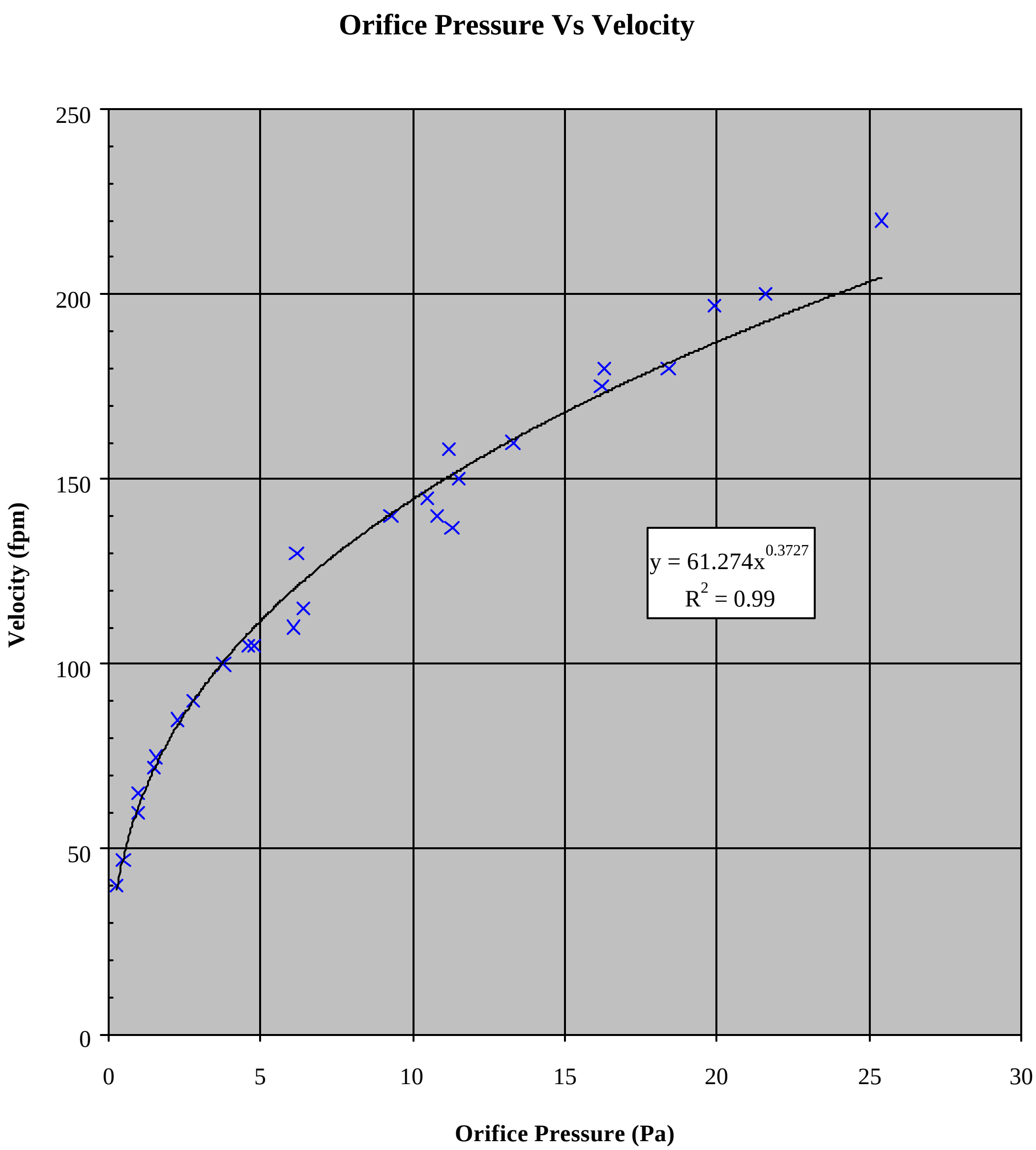
In addition to taking the numerical measurements, smoke was blown through the system and its behaviour on exiting was observed.

1. A screen sample was cut and placed into the holder.
2. The fan was cycled through it's power range and periodic pressure measurements were taken from both pressure taps.
3. The speed was set to 100 fpm and smoke introduced to the intake.
4. The resulting outlet pattern was observed and photographed.
5. The photographs were analysed to obtain the approximate distance to which the flow remained laminar. In most cases this was taken as the first "bulge" appearing. These seemed to represent the beginning of the vortex stream and were readily identifiable.
6. The preceding process was repeated for each of the screen samples available.
7. Once all of the screens had been tested a regression analysis based on the logs of screen pressure and velocity, and on free hole area, and was carried out using Microsoft Excel.

Results

Results can be found in more complete form in the attached spreadsheets, only analysis and graphs will be presented here.

Calibration



The above graph shows the raw data and the fitted curve. As evidenced both visually and by the R^2 value it can be seen that the fitted curve is a valid approximation of the actual results. Once completed, this result became the basis for the screen tests, allowing velocity to be measured from the pressure meter rather than the anemometer.

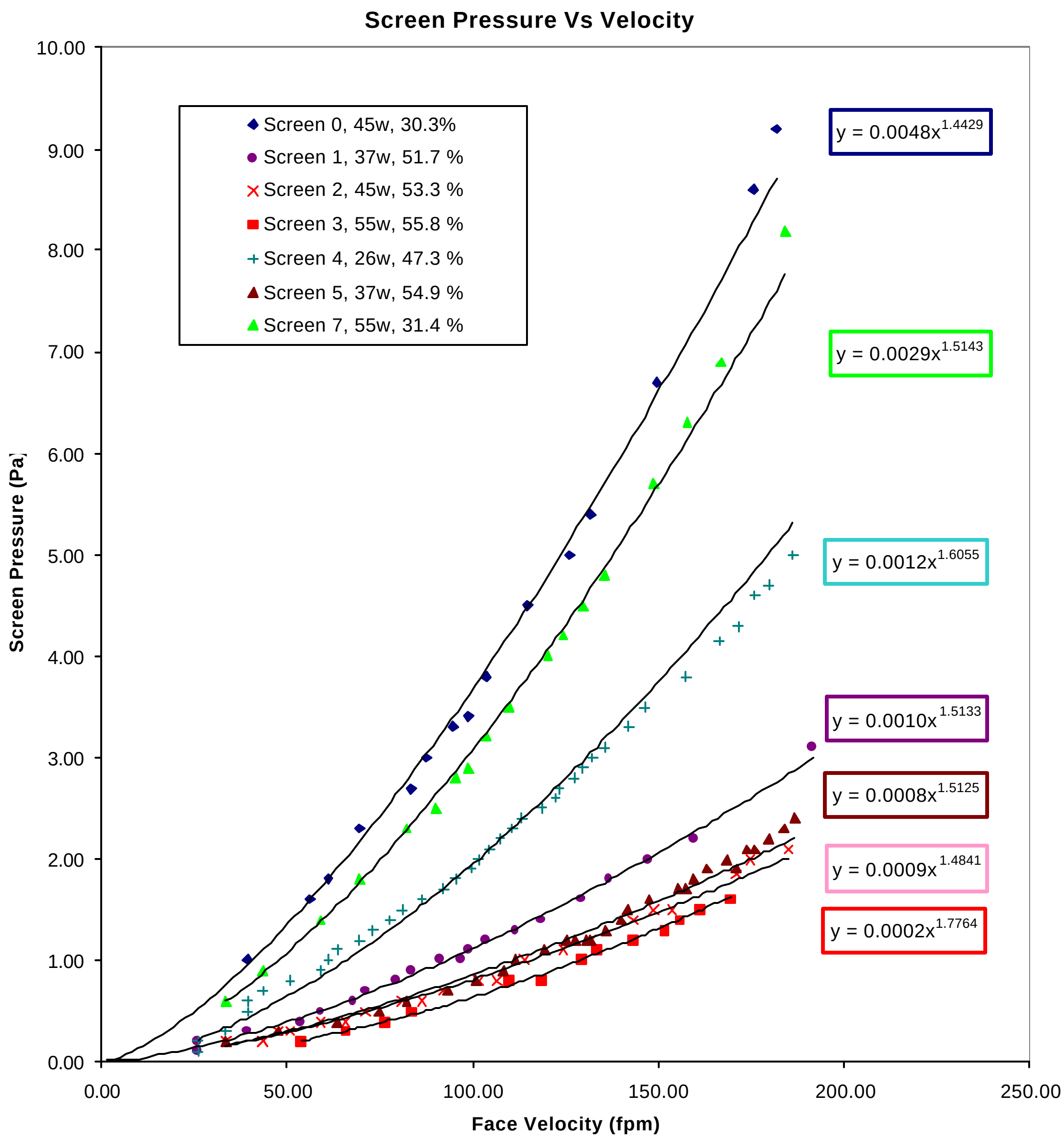
Screen Characterisation

The following screens were tested, the numbers assigned were arbitrary:

File Number	Wire Diameter (inches)	Mesh Number (wires / inch)	Wire Spacing (inches)	Free Hole Area
0	0.0045	100	0.0055	30.3%
1	0.0037	76	0.0095	51.7%
2	0.0045	60	0.0122	53.3%
3	0.0055	46	0.0162	55.8%
4	0.0026	120	0.0057	47.3%
5	0.0037	70	0.0106	54.9%
6	0.0037	120	0.0046	30.7%
7	0.0055	80	0.0070	31.4%

It can be seen that the wire diameters do not vary greatly (from 0.0026 to 0.0055). This was done to minimise the effects of differences in wire diameter and the geometric effects of the wire, thus allowing the wire diameter to be ignored as a variable.

The following graph was obtained on completion of the test runs:



The curves and equations were obtained by regression analysis from Microsoft Excel, fitting the points to a power law relation ($y=Ax^b$). They generally fit the results quite well, some deviation being evident on Screen 4, however it is not very large. Qualitatively it is possible to conclude that increasing the free hole area of a screen decreases the back pressure behind it and this is consistent for all of the tested screens.

A second regression analysis was performed to obtain an overall relationship between the three parameters. After several other attempts I discovered that relating log(Pressure), log(Velocity) and free hole area as a decimal percentage worked best. The results are presented below:

	Coefficients	*Standard Error*
Intercept	-1.631295759	0.083832161
X Variable 1	1.501876184	0.037382176
X Variable 2	-2.587207279	0.088615913

This results in an equation of the form:

$$y = 1.502x_1 - 2.587x_2 - 1.631$$

where y is log(Pressure), x_1 is log(Velocity) and x_2 is free hole area as a decimal percentage.

When converted into an equation in terms of Pressure (P), Velocity (V), and free hole area (A), in standard rather than logarithmic form it becomes:

$$P = \frac{V^{1.50}}{42.8 \times 10^{2.59A}}$$

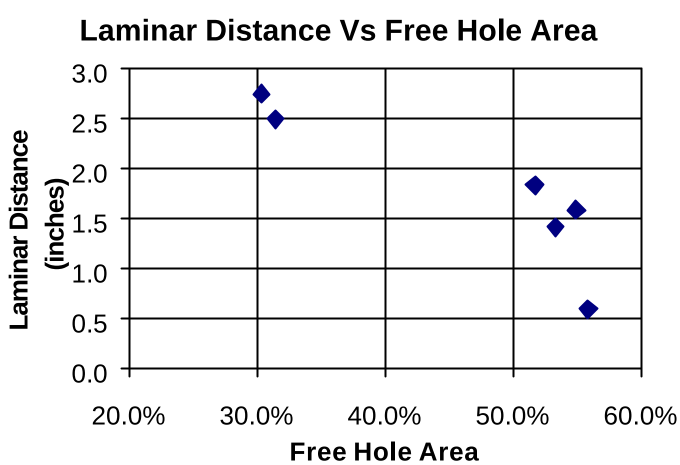
in units of Pascals, feet per minute and decimal percentage.

The high R values (close to 1.0) indicate the derived result agrees closely with the experimental data and thus it can be assumed that the result is valid.

Regression Statistics	
Multiple R	0.969112571
R Square	0.939179175
Adjusted R Square	0.938378901
Standard Error	0.099635941
Observations	155

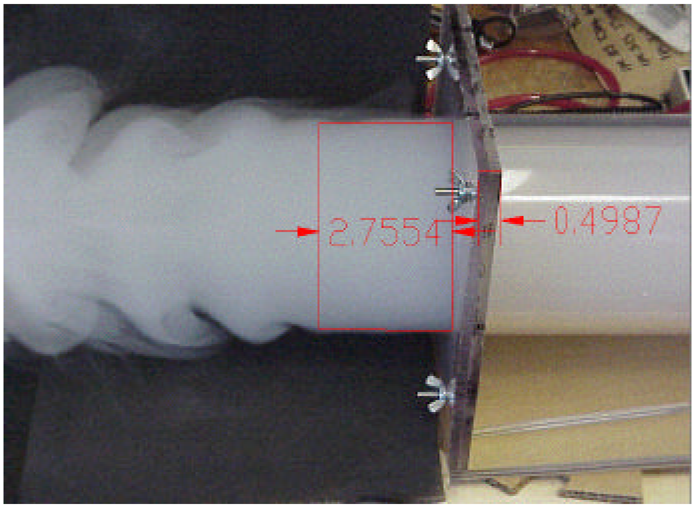
Flow Observation

The second phase in the screen test involved measuring the laminar distance of the flow upon exit. This was a difficult process as the flow could be disturbed very easily by room air currents and thus the results are far from exact.



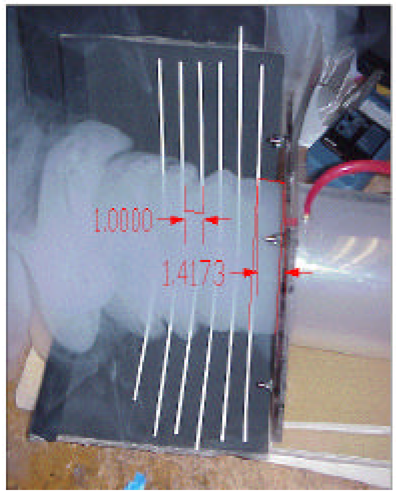
The graph to the right shows the general trend, but the results are too erratic to attempt to draw any mathematical relation. It is clear, however, that a smaller free hole area causes the flow to remain laminar for longer. It is unknown how this length will scale for different exit geometries and since it is quite small (less than 3”) it is unlikely this property will have relevance on a larger scale.

The photographs showing these results are given below. The photos illustrate a series of vortices developing at the edges of the flow. They hard to see clearly in the two-dimensional images, but they appear to mimic a Karman Vortex Street in three dimensions (see Screen 7 photograph). Further investigation was desired, but the failure of the smoke machine halted this investigation. These vortices seem to be the mechanism by which the flow disperses and spreads out (see Screen 2 photograph).

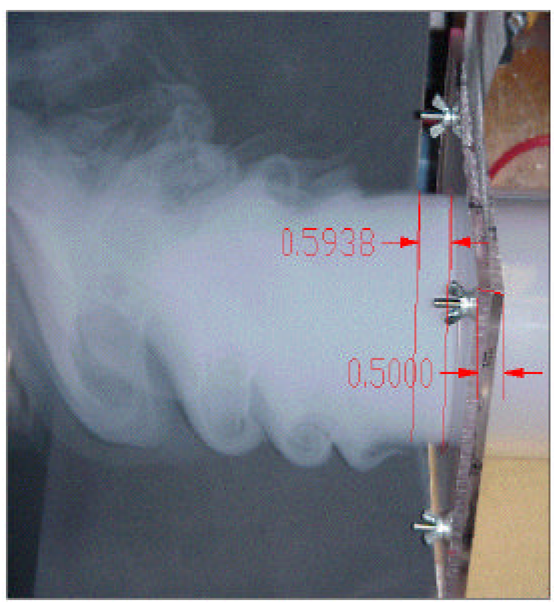


Screen 0 – 2.76 inches

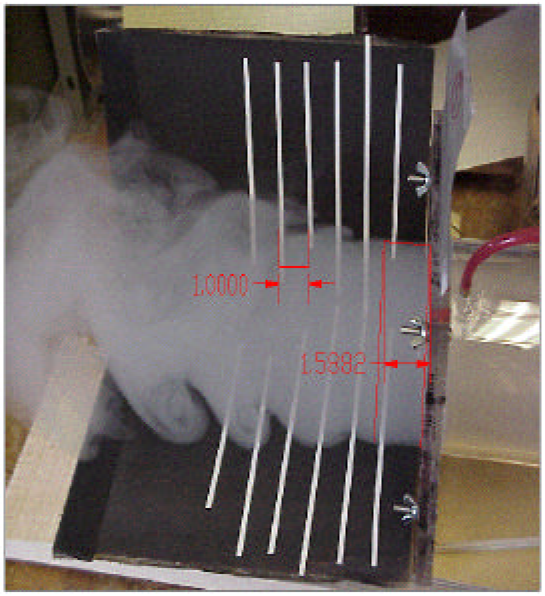
Screen 1 – 1.83 inches



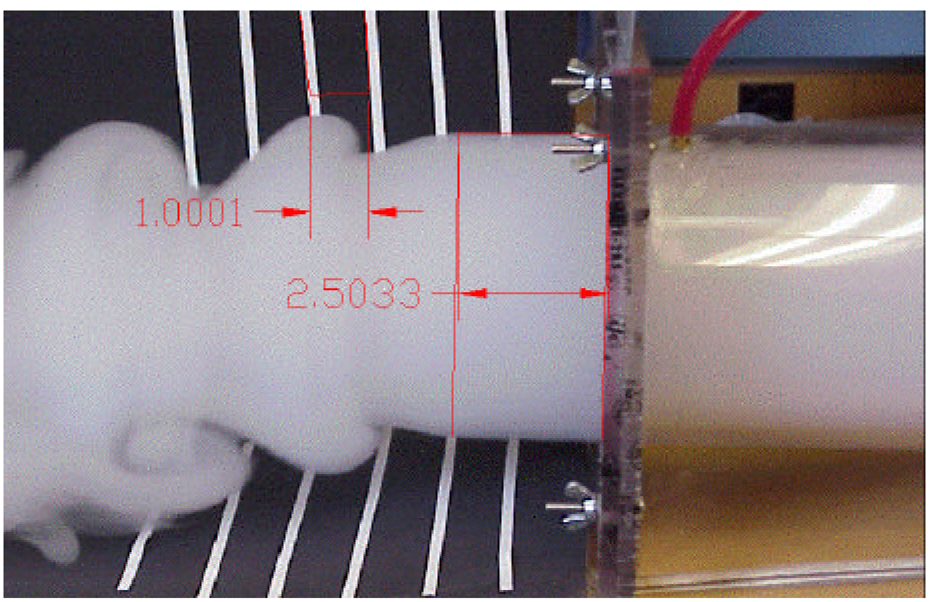
Screen 2 – 1.414 inches



Screen 3 – 0.5938 inches



Screen 5 – 1.59 inches



Screen 7 – 2.50 inches

Discussion

Experimental Errors

I believe there were only two significant sources of error in the experiment: the limit of reading of the pressure meter, and the effect of temperature changes on the airflow.

The only pressure meter available to me was only able to read as low as 0.1 Pa which was problematic since some of the measurements I was taking were in that range. For measurements around 2-3 Pascals, the limit of reading only introduces a 2-3% error, however when reading around 0.1 – 0.5, the potential error rises to 10-50%. This casts doubt on the validity of the readings in that range, however the graphs seemed to support the readings, fitting well in the higher ranges and often multiple measurements were taken in these areas to try to provide an average result. This affects the open screens (50+ % free hole area) more than the others since they have very low back pressures even up to 100 fpm, whereas the screens around 30% FHA exhibit much higher pressures in the range we usually operate in (50-100 fpm). The only way I can see to remedy this is by the use of a more sensitive manometer, however the one used was useful in that it provided a time average function, allowing values to be averaged over a five second period to reduce the effects of fluctuations.

I did not initially foresee the density / temperature problem as I did not expect the temperature at the lab to fluctuate as much as it did. During the weeks I was running tests it varied between roughly 60-100 degrees Fahrenheit. This temperature range represents an increase of about 50% in the kinematic viscosity of the air. This represents a change in the relationship between viscosity and density and will affect the velocity at which the flow becomes turbulent. It is unknown how significant an effect this will have on the results, however none of the results seem to deviate very far from what was expected so the effect seems minimal.

Measurement and Method

There were several factors that influenced the methodology of the experiment, these included the effects of auxiliary air flows in the room, difficulty in obtaining steady velocity measurements and the nature of the experiment itself.

The first and last considerations had the greatest effect on the visualisation experiments. When the laboratory door was open, the flows were significantly disturbed and broke down into turbulence much more quickly. This was a significant disadvantage as it meant that the door had to remain closed causing smoke to build up, making it both harder to see the current test run, and harder to breathe.

Velocity measurements were difficult to take because the anemometer had a very rapid response time, causing it to fluctuate wildly if the flow was not perfectly laminar. I believe a fan-type anemometer would have given better results due to its averaging effect.

The analysis of the exit flows was very difficult because the measurement process was largely arbitrary. I had to find a point that I could identify on each image, load each into AutoCAD, calibrate the image size using the calibration stripes, then finally mark off the distance I believed I wanted. This was a very slow and error-prone process, yielding results that can really only be considered qualitative.

Conclusions

Overall I believe the experiment was a limited success. I was able to obtain a numerical relation for screen pressure, velocity and free hole area that confirmed the expected results. The relation between free hole area and laminar distance was a new discovery and raises many questions about the geometric exit effects. When the results with and without the screen are compared, it is clear that the presence of a screen causes the flow to remain collimated for a much greater distance before it disperses. The necessity of the screen will be determined by the application and this experiment provides a method of determining required fan capacity when screens are used.

There is a great deal of work that can still be done in this area. The addition of more screens with free hole areas in ranges other than 30% and 50% would improve the validity of the regression analysis and more tests with a consistent wire diameter would verify or disprove my assumption that it is irrelevant. No investigation was performed on the effects of different geometries of the exit, i.e. square outlets instead, or even on different sizes of outlet. The pressure distributing ability of the screen would benefit from further investigation by widening the outlet beyond the edges of the tube. Separate experiments are being carried out to investigate the directional properties of such screens.